Pulmonary Function Changes Associated With Cardiomegaly in Chronic Heart Failure

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ABSTRACT

Background: This study examined the influence of increased cardiac size on maximal lung volumes, forced expiratory airflows, and the diffusing capacity of the lungs in heart failure (HF) patients compared with controls.

Methods and Results: Forty-one HF patients of New York Heart Association (NYHA) class: Group A = class I/II (n = 26) and Group B = class III/IV (n = 15) and an equal number matched controls (CTL) were recruited. Participants underwent echocardiography, spirometry, and posteroanterior and lateral chest radiographic evaluation (RAD) for volumetric estimation of the total thoracic cavity (TTC), diaphragm, heart, and lungs. Analysis of variance demonstrated no difference between groups for TTC volume ($P = .63$). RAD cardiac volumes (% TTC volume) were significantly different among all groups ($P < .001$). Echocardiograms determined left ventricular mass was elevated in the HF groups compared with the CTL group ($P < .001$) with no difference between HF groups. Lung volume (% TTC volume) was reduced as a function of disease severity ($P < .001$). RAD measures of cardiac volume demonstrated the strongest relationship with restrictive lung alterations (t-statistic = -5.627, $P < .001$ and t-statistic = -4.378, $P < .001$ for forced vital capacity and forced expiratory volume in 1 second, respectively).

Conclusions: These results suggest cardiac size may pose significant constraints on the lungs and likely plays a major role in the restrictive breathing patterns often reported in HF patients. (*J Cardiac Fail 2007;13:100–107*)

Key Words: Cardiomegaly, Roentgenography, Lung volume, Heart failure.

Chronic heart failure (CHF) is associated with mild to moderate changes in pulmonary function, including restrictive and obstructive changes as well as a reduction in lung diffusing capacity (DLCO).[1–3] Although heart failure induced causes of altered lung function remain unclear, they have been attributed to respiratory muscle weakness, pulmonary hypertension, changes in lung fluid balance, and chronic neurohumoral changes.[4–6] Because the lungs and heart both reside in a common enclosure (chest wall) and the cardiac muscle is less compliant than the lungs another potential contributor to the changes in pulmonary function in CHF relates to progressive cardiac enlargement within the thoracic cavity. Such changes in cardiac volume would be expected to result in primarily restrictive lung changes manifested as reductions in total lung volume and vital capacity.[2]

In addition, it may be expected that a relationship also exists between cardiac volume and maximal expiratory airflows as well as the DLCO. As cardiac filling pressures increase and pulmonary congestion progressively develops, blood flow may back up into the bronchial circulation and influence airway caliber resulting in airflow limitations.[7] Further, the reduction in DLCO with disease severity is likely related to lung fluid imbalance and chronic changes at the alveolar-capillary membrane.[3]

Epidemiologic studies have shown a link between pulmonary function and mortality, particularly related to cardiovascular events.[8–10] Although the causal link between lung function and cardiac mortality remains unclear, it may be associated with the progressive changes in cardiac size. Studies have implied a marginal link between cardiac size and lung function in CHF[1,11–14]; however, these studies are limited by echocardiographic measurement of left ventricular mass as opposed to total heart size and

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Manuscript received May 2, 2006; revised manuscript received August 19, 2006; revised manuscript accepted October 27, 2006.

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Supported in part by: National Institutes of Health grants HL71478 and HL07111.

1071-9164/$ - see front matter

doi:10.1016/j.cardfail.2006.10.018

1-dimensional estimates of the cardiothoracic relationship. Importantly, these studies may have inadequately represented the importance of changes in total cardiac size on lung function in relation to the constraints imposed by the thoracic cavity.

The focus of this study was to examine the relationship between radiographically determined cardiac volume and maximal lung volumes, maximal expiratory airflows, and DLCO in patients with long-standing but stable CHF. Further, we sought to determine if a commonly obtained echocardiographic measure of cardiac size in this population might be as predictive of lung function changes. We hypothesized that increased competition for intrathoracic space caused by changes in cardiac volume associated with CHF contributes to changes observed in pulmonary function and the commonly derived echocardiographic measures of cardiac dimension would inadequately predict these changes.

Methods

Population Characteristics

Forty-one CHF patients were recruited from the Mayo Clinic Heart Failure Service and the Cardiovascular Health Clinic (a preventive and rehabilitative center) between 2000 and 2004 (Table 1). Patients included those with a history of ischemic or dilated cardiomyopathy, stable CHF symptoms (>3 months), duration of HF symptoms >1 year, left ventricular ejection fraction ≤35%, body mass index <35 kg/m^2, and current nonsmokers (past 15 years) with a smoking history <10 pack-years. Patients were treated with standard optimized medications for heart failure at the time of the study. An equal number of control participants were recruited via advertisement from the surrounding area and were matched with the CHF group for age, gender, and height. Control participants (CTL) had normal cardiac function (ejection fraction >50%), without history of hypertension, lung disease, or coronary artery disease. All participants gave written informed consent after being provided a description of study requirements. The study protocol was approved by the Mayo Clinic Institutional Review Board; all procedures followed institutional and Health Insurance Portability and Accountability Act guidelines.

Overview of Protocol

Participants underwent posteroanterior (PA) and lateral (LAT) chest radiographs, echocardiography, and spirometry. The CHF patients were divided into 2 groups by New York Heart Association class as follows: class I and II, n = 26 (Group A) and class III and IV, n = 15 (Group B).

Radiographic Volumetric Evaluation

The PA and LAT radiographic views were used to make volumetric estimations of the total thoracic cavity (TTC), diaphragm, cardiac, and lungs based on the assumptions of a partial ellipsoid as initially described by Barnhard and colleagues[15] and later by Glenn and Greene as well as others.[16–18] This methodology has been shown to be valid and reliable.[16,17] Details of this technique from our laboratory, in a companion cohort of CHF and matched controls, are published elsewhere.[19] Briefly, the inner most edge of the intrathoracic cavity and outer most edge of the cardiac silhouette on both radiographic views were manually traced on a digitizing tablet (AccuGrid A43BL, Numonics Corp, Montgomeryville, PA) with data exported to a digitizing software program (Didger 3, Golden Software Inc, Golden, CO) on a personal computer for offline analysis. Coordinate data were used to make linear measurements for the volumetric computation. The volumetric measures for total thoracic cavity volume (TTCV), cardiac volume (CV), and the total radiographic lung volume (total thoracic cavity, diaphragm, cardiac, and lungs) were calculated as follow: TTCV = $(1/4\pi)^{*}D_1^{*}D_2^{*}D_3$ where D_n represents width, depth and height of the PA and LAT views, CV = $(1/6\pi)^{*}D_1^{*}D_2^{*}D_3$ where D_n represents diameters of the atrium and ventricles in the PA and LAT views and TLC = TTCV = (CV+DV+PBV+PTV) where DV represents diaphragm volume, PBV pulmonary blood volume and PTV, parenchymal tissue volume (see previous article[19]).

Echocardiographic Evaluation

Doppler and 2-dimensional echocardiographic measurements were performed according to the recommendations of the American Society of Echocardiography.[20] Left atrial dimension, left ventricular (LV) mass, LV internal dimension during systole and diastole, interventricular septal thickness, LV posterior wall thickness, and left atrial end-diastolic dimension were measured. LV mass was calculated using the formula of Troy and colleagues.[21] LV mass index was calculated as left ventricular mass divided by body surface area. The LV ejection fraction was calculated using the modified Simpson's rule.[22] Transmitral inflow velocity was obtained from a 2-dimensional apical window with the pulsed-wave Doppler function facilitating the calculation of maximal early flow velocity (E), maximal late flow velocity (A), the ratio of maximal early to late flow velocity, and deceleration time of the early diastolic filling.

Pulmonary Function Evaluation

Participants underwent spirometry evaluation including, forced vital capacity (FVC) and assessment of maximal expiratory airflows including forced expiratory volume in 1 second (FEV_1), mean forced expiratory flow between 25% and 75% of the FVC (FEF_{25-75}) and maximal FEF (FEF_{max}). Participants also underwent assessment of the diffusing capacity of the lungs for carbon monoxide and measurement of alveolar volume (TLC_{VA}) using the single breath method. Spirometry and DLCO measures were collected in accordance with the American Thoracic Society standards.[23,24]

Statistical Analysis

Statistical analysis and graphic presentation were accomplished using SPSS (v 12.0, Chicago, IL) and Graphpad Prism (v 4.0, San Diego, CA). One-way analysis of variance (ANOVA) was used to test means across the groups with Bonferroni post-hoc analysis where appropriate. Unpaired *t*-tests were used to compare the control and the entire CHF group. Partial correlations were calculated between radiographic measures and measures of CHF severity adjusting for age, height, weight, body surface area, smoking history, and systolic and diastolic blood pressure. Standardized β coefficients were calculated from linear regression. Fischer's exact test was used to test for differences in categorical variables. Statistical significance was set at $P < .05$ for all analyses. Data are presented as mean ± standard deviation (SD) or number and percent of the group.